Systems Engineering Assessment & Workforce Development Plan

Final Technical Report SERC-2012-TR-026

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Principal Investigator: Brian Sauser, Stevens Institute of Technology

Co-Principal Investigator: Robert Cloutier, Stevens Institute of Technology

Team Members

Bruce Barker, Stevens Institute of Technology

William Robinson, Stevens Institute of Technology

Dinesh Verma, Stevens Institute of Technology

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14. ABSTRACT

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ABSTRACT

Research in the area of systems engineering competency has yielded significant Department of Defense (DoD) policies, guidance, and reference materials pertaining to applying systems engineering (SE) policy, standards, and best practices for higher performance on major acquisition programs. These best practices are not universally applied across the DoD and particularly to the US Army Research, Development, and Engineering Command (RDECOM). Further research is needed to enable acquisition, research, and development efforts with the ability to tailor existing documentation and augment, as needed, to better focus the breadth and depth to which policies, guidance, and extent of documentation is utilized.

This research task assessed the current state of systems engineering maturity within RDECOM to benchmark its position relative to its practices to establish a plan/roadmap to aid RDECOM in creating a Systems Engineering Organization Standard Process appropriate for a world class Research & Development organization. This research task utilized an RDECOM analysis of its SE competencies to develop appropriate platforms to fill competency gaps and deliver appropriate training content and competency assessment tools to provide qualitative and quantitative guidance to RDECOM in the development of a SE organizational competency.

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1 INTRODUCTION

In October 2004, the United States signed into law the Federal Workforce Flexibility Act requiring each federal agency to evaluate, on a regular basis, its training programs and plans with respect to the accomplishments of its specific performance plans and strategic goals. This law was in part a response to the need for advanced human capital with improvements in labor productivity and profitability to address ever-increasing uses of new and advanced technology solutions. Secondly, this law was responding to the large deficit in technical leadership in the Federal Government (OPM 2009).

The challenges for developing human capital with a high technical competency while filling a technical leadership gap have not been confined to the Federal Government or its technical domains. Other fields, such as culinary and healthcare, have also identified these emerging and growing issues (Calhoun, Dollett et al. 2008). While some technical domains have established legacy in the definition and development of human capital, e.g. mathematics, physics, mechanical engineering, there are growing fields of study that have become critical to effective and efficient technical success that are far less defined in the development of human capital. One such field is systems engineering (SE) (Shenhar and Sauser 2009), which has only recently begun to better define how the competency in this field is developed and matured (Squires and Larson 2009). For the advancement and development of human capital in this field, the Federal Government and its agencies will need to expand their career development programs. Therefore in support of this growth, any career development program is more easily integrated within an organization when it is based on competencies needed to perform the job (Mirabile 1985).

As such the US Army Research Development and Engineering Command (RDECOM) has continued to advance the domain and practical knowledge of systems engineering to optimize their ability to develop systems with ever-increasing environmental and technical complexities. Therefore, in the development of human capital for the Department of Defense (DoD) and RDECOM, this research task assessed the current state of SE maturity within RDECOM to benchmark its position. The SE knowledge gaps present will be utilized to establish a plan/roadmap to aid RDECOM in establishing a Systems Engineering Organization Standard Process appropriate for a world class Research & Development organization. In preparation for this task, RDECOM performed a gap analysis to determine the competency needs SE. This task utilized this analysis to develop appropriate materials to fill this gap and deliver appropriate training content and competency assessment tools to provide qualitative and quantitative guidance to RDECOM in the development of a SE organizational competency.

2 APPROACH

In the creation of a career development and competency model for an organization, it becomes a combination of observable and applied knowledge, skills and behaviors and how the human capital ultimately creates value to what is actually accomplished, while focusing on the behavior rather than personality traits of the human capital (Jauhari and Misra 2004). Creating competency-based career development and a supporting model consists of the analysis, assessment, and evaluation of necessary job skills. This project was executed within three phases as describe in Table 1. The results of this three-phased approach was a SE competency development and assessment platform that was used to train and assess the fundamental knowledge and skills of a RDECOM SE workforce. The goal of this work is to advance the state of knowledge and practice of SE for RDECOM.

Table 1: Project Phases

Phase	Activity	Outcomes
Discovery	Assessment of current career development practices and competency models in SE as utilized in RDECOM. Survey current RDECOM practices and needs through Voice of the Customer with key personnel and the RDECOM SE Integrate Product Team (IPT).	Understanding of the state of RDECOM needs for skill levels and define applicable competency requirements in SE.
Analysis	Analyze gaps, targets, and strategic intent based on the results of the Discovery phase to formulate a position for executing a competency development and assessment platform.	Preliminary version of a SE competency development and assessment platform.
Synthesis	Execute the competency development and assessment platform via a spiral development approach.	Creation of a SE competency development and assessment platform for further execution within RDECOM and throughout DoD where applicable.

3 RESULTS

PHASE 1: DISCOVERY

Phase 1 was intended to determine an initial set of competency requirements for RDECOM SE. These requirements would be based on organizational needs, gaps, and future developments as they related to building a SE knowledge base in RDECOM. The key stakeholder in guiding this development was the RDECOM SE Integrated Product Team (SE IPT). The SE IPT consist of representatives from the lead organizations within RDECOM that practice SE and is the governing body of all SE policy and practices within RDECOM. As a baseline, the SE IPT developed an initial set of competency requirements in SE that were necessary for developing a knowledge base in SE within RDECOM (see Appendix A). This set of requirements was further prioritized into a set of competency modules. While these modules did not cover the entire set of requirements or SE competencies, they were defined as the key SE competencies of greatest priority to RDECOM. They were:

- Modules 1: Approaching Problems
  - Critical vs. Intuitive Thinking
  - Problem Solving
  - Systems Thinking
  - Soft Systems vs. Hard Systems Methodology
  - How to Model Problems
- Module 2: Engaging Stakeholders
  - Voice of the Customer
  - Perspectives: Identifying Potential Customer Voices
  - Types of Requirements
  - Functional vs. Non-Functional
  - Capabilities and Characteristics
  - Kano Theory
  - Listening to the Customer
  - Methods for Capturing VoC (Voice of the Customer)
  - QFD (Quality Function Deployment) and House of Quality
- Module 3: Defining the Solution Space
  - Pugh Matrix
  - Context Diagrams and Scenario Diagrams
  - Developing the System Requirements
  - System Architecture

PHASE 2: ANALYSIS/PHASE 3: SYNTHESIS

Phase 2 transitioned the results of Phase 1 into a set of training modules supported by proper assessment methods. This phase had three developments: training objectives, training materials, individual assessment tool, and course assessment tool. As part of Phase 3, the competency development and assessment platform was executed via a spiral development approach that allowed for refinement and assessment.

TRAINING OBJECTIVES

Based on the three modules defined from Phase 1, a set of objectives was establishing from initially defined content and topics. These objectives were written in the context of Bloom's Taxonomy (Bloom 1956), which articulates the cognitive domains involved in knowledge and the development of intellectual skills. These objectives were refined as the content of the modules evolved, and the final objectives are listed in Appendix B.

TRAINING MATERIALS

An initial set of training materials was developed based on the outcomes of Phase 1 from pre-exiting training materials developed by Stevens Institute of Technology. This content was refined based on numerous iterative reviews with either the RDECOM Project Headquarters at Aberdeen Proving Ground or the RDECOM SE ITP (see Figure 1 for a timeline of this review process). During this review process numerous refinements were made before the first deployment of the materials on June 25-29, 2012 at the US Army Aberdeen Proving Ground (APG) in Aberdeen, MD. The content went through further refinement after the APG offering, before it was offered at the US Army Armament Research Development and Engineering Center (ARDEC) at Picatinny Arsenal, NJ on July 16-19, 2012. Each course finished with a Technical Review presentation made by a group of 3-5 students. For the Technical Review, they were responsible for giving a 20-minute presentation showing their analysis of the in-class case using the systems engineering artifacts they developed and refined throughout the week. Presentations were then evaluated based on the criteria specified in Appendix C. The outline of the presentations was as follows:

i) Problem Statement
ii) Systemigram
iii) Stakeholders (Active and Passive)
iv) Stakeholder Requirements and Priorities
v) Potential System Concepts
vi) Pugh Matrix
vii) Context Diagram
viii) Functional Analysis
ix) QFD
x) System Requirements – Functional
xi) System Requirements – Input/Output
xii) Non-Functional Requirements

xiii) Functional Architecture
xiv) Logical to Physical Allocation

Some of the notable changes made during these iterations were:

- The incorporation of content being developed under RT4 "Developing SE Technical Leadership" (see: http://www.sercuarc.org/projects/view/6).
- A final module on Project Planning was replaced with a module on Technical Reviews and the students would perform a readiness review on the final day of training.
- The reduction of the class from a 5-day class to a 3-day class to better accommodate the loads and demands of the RDECOM personnel.

The final outline of the course was as follows:

Syllabus:

Day 1: Problems with Problems / Types of Stakeholders
- Welcome and Introduction
- General Thinking Overview
- Problem Solving
- Problem Definition
- Voice of the Customer

Day 2: Engaging Stakeholders
- QFD/House of Quality
- Context Diagrams
- Pugh Matrix
- Functional Analysis

Day 3: Requirements to Architecture
- Developing System Requirements
- Functional Architectures
- Physical Architectures
- Technical Baselines and Reviews
- Course Evaluation
- Final Exam

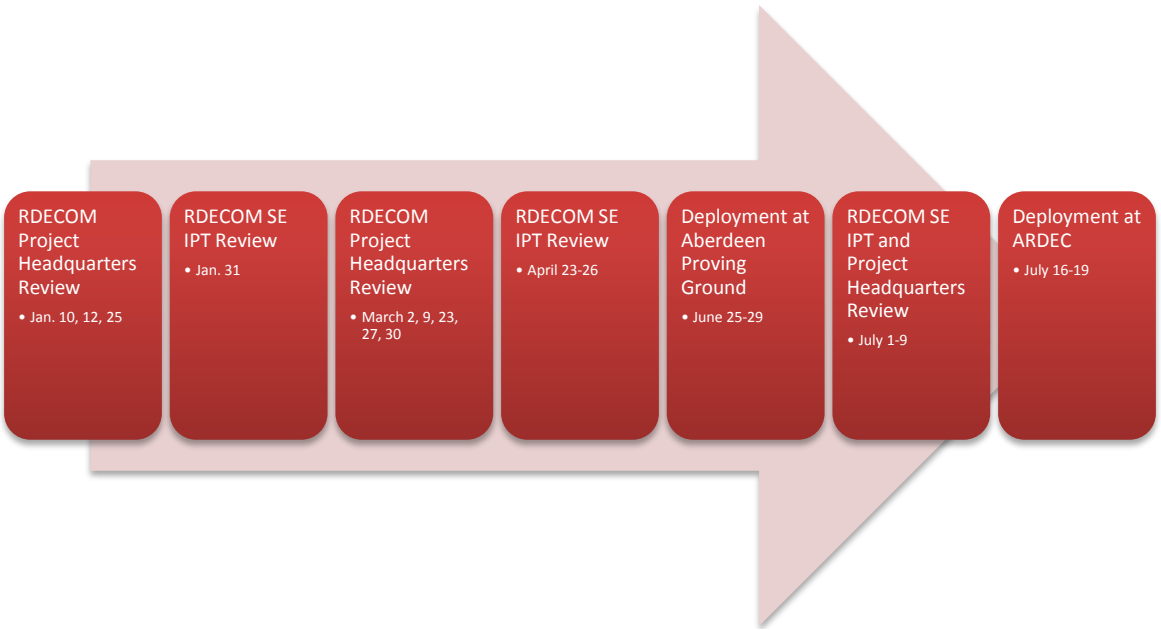


Figure 1: Development Timeline

INDIVIDUAL ASSESSMENT TOOL

One of the requirements established by the SE IPT was that the students be held accountable for the materials and having an ability to effectively assess their competencies. As such a pre- and post-exam was developed to test the student's SE knowledge prior to the course and after the course. Appendix D is the exam with the answers and question weighting. The results of the implementation of this examination will be discussed in the Assessment section of this report.

COURSE ASSESSMENT TOOL

A final requirement of the SE IPT was the ability to assess the course, the student's views of the course, and their perception of the course's ability to achieve the learning objectives. This assessment tool is shown in Appendix E.

4 ASSESSMENT

Fundamental to this project was the ability to assess the course, instructors, learning outcomes, and student's knowledge/performance of SE. The following is a summary of those assessments.

COURSE ASSESSMENT

ABERDEEN PROVING GROUND, JUNE 25-29

The following is the executive summary provided to RDECOM on the course assessment. A detailed analysis and student feedback is in Appendix F:

> *The course went well. It was completed comfortably in four days instead of the allotted five days without rushing the lectures or exercises. Some positive observations that may be gathered from the comments on the student assessments:*
>
> - *Overall, the material was well received by the students*
> - *The students are hungry for tools to help them in the systems engineering process*
> - *They seem to appreciate approaches to formalize the systems engineering process*
> - *The format of the class – lecture then do – was well received*
> - *The more significant recommendation for course improvement was related to the examples in the lecture material. The example that runs through the course material is Amazon.com. The students overwhelming believe the example should be one from RDECOM/Army so that it is more relevant to them.*
> - *There was a number of requests for similar training on the "right hand" side of the Systems engineering "V"*
>
> *Finally, some observations from the professor's perspective:*
> - *While it is understood why the IPT decided to take the approach on the RFI problem utilized for the class exercise, the lack of information was a negative. Few of the students had any idea what the RFI was requesting – it was just too sketchy to work from, and that uncertainty got in the way of learning.*

ARDEC, JULY 1-9

The following is the executive summary provided to RDECOM on the course assessment. A detailed analysis and student feedback is in Appendix G:

> *The course went well. It was completed comfortably in three days. The pace was comfortable. Positive observations that may be gathered from the comments on the student assessments:*
>
> - *Overall, the material was well received by the students*

- *The students liked the requirements writing material, and the QFD material*
- *Class exercises were very helpful*
- *There was mixed feedback on Systemigrams this time. Some liked the approach, some thought they were too informal.*
- *There is strong interest in a similar course to address the right side of the "V".*
- *A contrast to the first offering at APG, is that this group were much more comfortable with the in-class robot deployment system – and the lack of definition of the problem.*

STUDENT ASSESSMENT

Students received a pre-examination within ten minutes of arriving to the class and had 30 minutes to complete the exam. At the end of the course, they were asked to repeat the exam with 30 minutes to complete the exam. Results of the pre- and post-exams are shown in Tables 2 and 3. All exams (APG and ARDEC) were graded by the same faculty member to assure consistency in grading. In summary, the following is how the exams were graded:

[1] A 5-point scale (1-5) was used for each question. If the student did not answer the question, they received a 0. If the question had multiple parts, the points were distributed equally across the parts.
[2] The pre-exams were graded first and then the post-exams. The student's pre-exam was not used as a baseline or comparison for determining their post-exam grade on any one question. Pre- and Post-exams were graded independently.
[3] Scores per question were input into an Excel spreadsheet as raw data. These scores were then evaluated using the weighting (WT) specified per question.
[4] Final scores were reported on a 0-100 scale.

Some observations about the pre- and post-examinations, APG, and ARDEC:

- Some students did not preform as well on the post-exam on a few questions. While it is not clear why, it was the interpretation of the grader that some students may have given up and wanted to finish the exam without properly answering the question.
- The APG class used an open book format for the post-exam, while the ARDEC class did not. It should be expect that the APG post-exams would have a higher score than the ARDEC post exams.
    - APG class average score: 82 (15)
    - ARDEC class average score: 74 (14)

- The ARDEC personnel have received more fundamental SE training coming into the class, and would have better pre-exam scores.
  - APG class average score: 33 (12)
  - ARDEC class average score: 53 (20)
- Based on the previous two observations, one would expect the delta between pre- and post-exams to be greater for the APG class than the ARDEC class.
  - APG class delta score: 48 (18)
  - ARDEC class delta score: 21 (14)

Table 2: APG Pre- and Post-Examination Grades

Statistics	Pre-Exam Score (0-100)	Post-Exam Score (0-100)	Exam Score Increase Pre to Post
Mean (sd)	33 (12)	82 (15)	48 (18)
Mode	42	98	
Median	35	85	
Max	60	98	73
Min	12	40	4

Table 3: ARDEC Pre- and Post-Examination Grades

Statistics	Pre-Exam Score (0-100)	Post-Exam Score (0-100)	Exam Score Increase Pre to Post
Mean (sd)	53 (20)	74 (14)	21 (14)
Mode	37	94	
Median	63	73	
Max	77	94	56
Min	6	41	2

5 Future Developments

The results of this research task were to help start a SE competency development and assessment platform for the RDECOM workforce. This was based on a set of competency requirements in SE as defined by RDECOM (Appendix A). Addressing all of these requirements was out of the scope of this research task, so the focus was on the Technical Processes that comprise "the left side of the 'V'" (see Figure 2). Further advancing this research task would be to develop the appropriate platforms to address the "right side of the 'V'" and the corresponding Technical Management Processes.

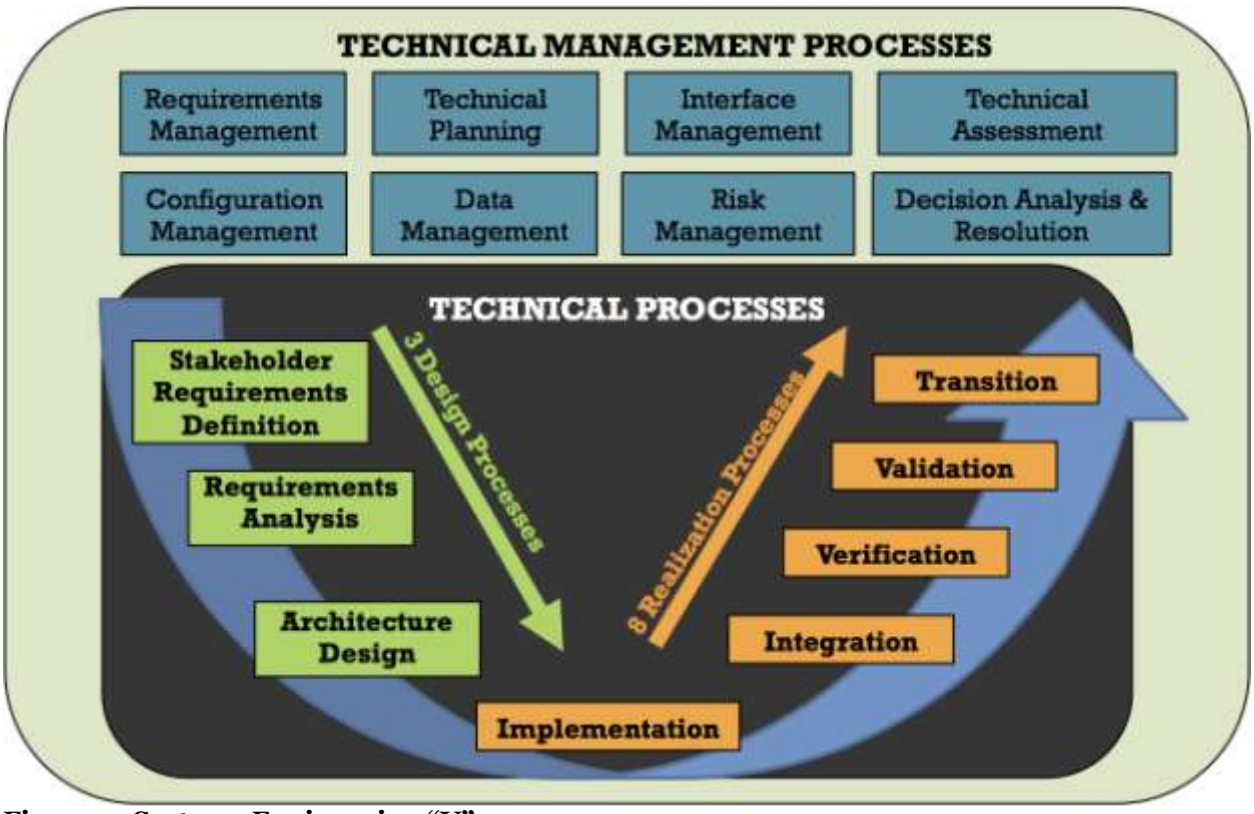


Figure 2: Systems Engineering "V"

It would also be recommended to:

- Further evaluate the current body of knowledge in career development and competency models in industry and other government agencies.
- Re-evaluate key competencies developed for RDECOM and consider broaden key parameters to include SE proficiencies needed to support workloads outside (other than) RDECOM.
- Assess the entire DoD population of SE for existing proficiency levels and competency needs.
- Develop and initiate a development process development for certification approvals in SE.
- Develop SE certification levels/strata, competency definitions/elements based on population assessment and execute a validation effort for certification assessment tools and assignment and certification approvals.
- Address SE *Behaviors* as part of the competency development and assessment plan. The most effective competency models consider the behavioral traits (Ryschkewitsch, Schaible et al. 2009) as a direct correlation to optimal competency performance.
- Expand the SE knowledge interchange to incorporate multiple platforms and medium. Building SE competencies, behaviors, and skill levels for the RDECOM SE workforce will take a comprehensive and systematic knowledge interchange approach using an appropriate mixture of standard and advanced media. Thus, a

review of new and emerging knowledge interchange media (e.g. social media) could be assessed to determine how it can be effectively used with or to enhance current medium. The appropriate media could be matched with the *Behaviors* and *Competencies*, so as to develop a systematic SE career development plan that is the most effective. In the identification of appropriate media indicators, key performance criteria could be considered such as creativity, innovation, communication, collaboration, critical thinking, and technology. See Table 4 for an example of this multi-platform knowledge model.

Table 4: Systems Engineering Knowledge Interchange Media

Knowledge Interchange Platforms	*Delivery Method*	*Duration*	*Credit Type*	*Learning Type*
Training 1 (Short-range)	Classroom Online Seminar Conference/Prof. Meeting	1-3 days	Continuing Ed. Certification (not for credit)	Task-based or Content-based
Training 2 (Mid-range)	Classroom Online	4+ days	Continuing Ed. Certification (not for credit)	Task-based or Content-based
College Course	Classroom Online	40+ contact hrs.	College (credit)	Content-based
Advanced Degree	Classroom Online	12+ months	Certificate Masters Ph.D.	Content-based
Personal Experience	Rotation On-the-Job Participant Observation Experience Accelerator	3+ days to 4+ months	None	Task-based

Figure 3 represents a *Career Development and Competency Model (CDCM) Architecture* that can be used bring the SE *Competencies*, *Behaviors*, and *Knowledge Interchange Media* into a comprehensive and systemic plan that can not only build, but sustain, the careers of Systems Engineers in RDECOM. The development and execution of this plan will require more than standard practices and approaches, but must look for novel approaches to developing Systems Engineers. RDECOM is addressing today's and tomorrow's challenge, so its Systems Engineers will have to gain standard and emerging knowledge in SE. Important to this is the integration of *Behaviors* with *Competencies* while building and transferring these through *Knowledge Interchange Media*. Figure 3 is a context-architecture of the development of the *CDCM Plan*. The end objective of this would be to have an executable plan leading to defined *Skill Levels* and organizational *Certification*.

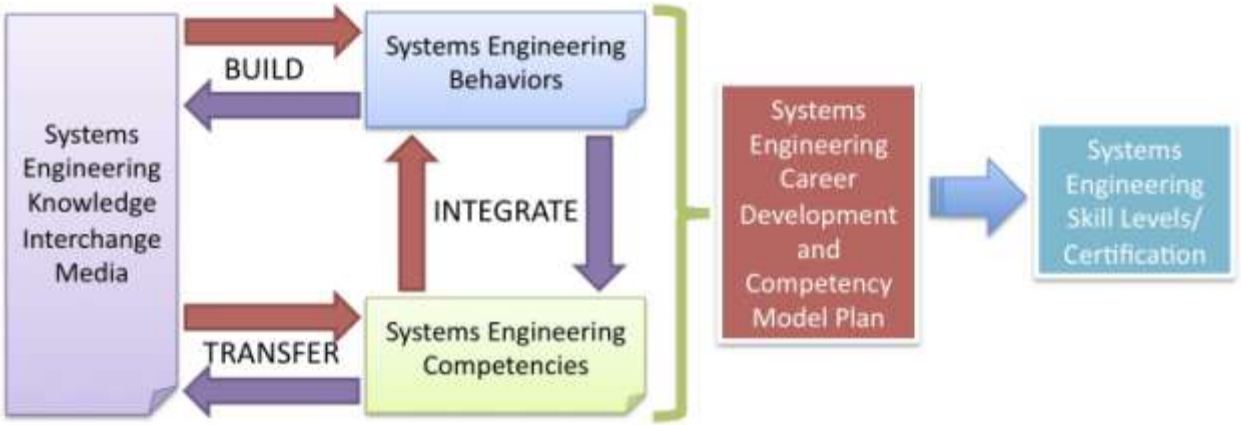


Figure 3: Career Development and Competency Model Architecture

APPENDICES

APPENDIX A: INITIAL RDECOM SE COMPETENCY REQUIREMENTS

Topic Area	Requirement
Introduction	Course Objectives: State WHY are you getting trained with RDECOM focus
	Purpose: Train RDECOM SE best practices/process areas, technical reviews. Facilitate Communication/Integration across RDECOM
	RDECOMs Role in the Army and Impact throughout the program lifecycle: Develop the enabling technology for PoRs, Acquisitions Matrix Support, Materiel Solution Provider and Technical Advisors, Addressing O&S Cost Drivers
	Overview of current SE initiatives; WSARA, Better Buying Power
	Overview how SE is executed on Joint Programs within RDECOM (Cross-Command)
	SE Roles & Responsibilities (part of OPORD Overview)
System Thinking	System Concept overview
	Explain the SE Linkages Products/artifacts/processes to program objectives and decision points
	Aspects of Development that need to be address across the Lifecycle Phases; System Under Development, M&S, Test Infrastructure, Development Infrastructure/Environment (SW development environment)
	System Architecture Overview
	CONOPs, How is the system employed
	Engineering Resilient Systems
Project Management Areas	Project Planning Essentials
	Project Plan & Quarterly Review Process Outlined
	Team Building - Teaming Structure
SE Process Areas - *Illustrate inputs/outputs/ activities/ recommended tools/artifacts*	Running Application/Example -
	More depth in how to execute SE Process areas - include MOEs/MOPs Flow-down & Use
	Stakeholder Requirements Definition
	Requirements Analysis
	Architectural Design
	Implementation
	Integration
	Verification

	Lifecycle Cost Estimations (LCCE)
	Peer Review
	Validation
	Tech Planning
	Technical Assessment
	Configuration Management
	Data Management
	Requirements Management
	Risk Management
	Interface Management
	Transition
	Decision Analysis and Resolutions (DAR)
Tools	SE Tools Overview
	DashBoard Overview
	MBSE Overview

APPENDIX B: COURSE DESCRIPTION AND LEARNING OBJECTIVES

Course Description:

Research on advances in systems engineering has yielded significant DoD policies, guidance, and reference materials pertaining to applying systems engineering policy, standards, and best practices for higher level TRL/Major Acquisition programs. A closer review of Lower TRL research and development efforts reveals that this area is in an immature state in terms of identifying and providing applicable policy, standards, and best practices to assist these efforts. This course will help aspiring technical leaders develop and refine their skills in analyzing systems, synthesizing holistic solutions, and making sound judgments in the presence of ambiguity, rapid change, and non-technical constraints. The course will be a mixed model delivery of lectures, case studies, perspectives, and experiential learning.

Day 1 Learning Objectives

Objective
Translate *and* ***Explain*** *system thinking objectives into a problem statement that can be solved by traditional engineering techniques and skill sets.*
Diagram *and* ***Discriminate*** *the environment, system under development, and suitability of a systems solution using systems thinking approach.*
Apply *systems thinking tools and techniques to better understand the enterprise and technology issues, which will affect the design of a system and translates these into system requirements.*

Day 2 Learning Objectives

Objective
Evaluate *and* ***Describe*** *customer needs, active and passive stakeholders and their perceptions of a system of interest.*
Identify *essential features that are critical to satisfy customers and* ***Distinguish*** *where to focus further improvement efforts.*
Create *a set of artifacts (i.e. Context Diagram, QFD, Pugh Matrix) that identify key drivers of customer satisfaction and needs.*

Day 3 Learning Objectives

Objective
Demonstrate *the concept of Use Case Scenarios to better understand the "Capabilities" that the stakeholders require.*
Translate *the output from the development of use case scenarios and system objectives into system requirements and* ***Critique*** *the characteristics of "good" requirements.*
Comprehend *the importance and the role of the system architecture and associated derived requirements in the development and project planning process.*
Assess *a system of interest using the concepts and artifacts learned in class and* ***Arrange*** *this in a coherent and effective Review.*

APPENDIX C: FINAL PROJECT SPECIFICATIONS

Project Problem:

Technical Reviews assure that the systems development and technical baselines are within the system objectives to satisfy the customer. A Technical Review provides management decision points where trade-offs can be exercised to maintain convergence on a system solution within the constraint boundaries. Your team will be responsible for executing a Technical Review presentation of your proposed system solution based on the RFI provided in Day 1 to ensure that the resulting set of requirements agrees with customer needs and expectations and that the system under review can proceed.

Original RFI: 541st EN CO, 54th EN BN RCP Soldiers request a method to deploy and operate their robots without exiting their vehicles
Request: Develop and integrate an exterior mounted RDS with a low profile.

What is Due:

Your team will be responsible for giving a 20 minute presentation showing your analysis of the case using the artifacts you developed and refined throughout the week. Your presentation should include the following artifacts articulated through the tools and techniques learned in class:

1. mission objectives
2. candidate system architecture
3. top-level system requirements
4. operational interfaces
5. preferred system concept
6. enabling technologies

Your presentation will be assessed upon:
1. System objectives are clearly defined and stated and are unambiguous.
2. The preliminary set of requirements satisfactorily provides a system that will meet the objectives.
3. The system is feasible. A solution has been identified that is technically feasible.
4. The concept evaluation criteria to be used in candidate systems evaluation have been identified and prioritized.
5. The presentation utilized the learned artifacts to demonstrate the learning objectives.

Evaluation criteria:

Rubric:	**0**	**1**	**2**	**3**	**4**
Technical Requirements Did it include the artifacts articulated through the tools and techniques learned in class?					
Analysis and Synthesis Was information effectively synthesized from the tools and techniques learned in class to perform an analysis of the data or information.					
Presentation and Writing Did it flow well? Did it have logical progression? Was information clearly presented? Was it easy to understand? Were graphs, tables, and visuals used? Did it have organization and clarity					

APPENDIX D: PRE- AND POST-EXAMINATION

1. What is the difference between analytical and intuitive thinking? Which is better in systems engineering?

Weight: 10%

Intuitive thinking relies upon context, ambient conditions, modular responsivity, task difficulty, task ambiguity, and/or affective state.

Analytical thinking relies upon education, training, critical thinking, logical competence, rationality, feedback, and/or intellectual ability.

2. Define the concept of "stakeholders." Describe the difference between active and passive stakeholders.

Weight: 5%

Active: Individuals, Entities, Other Systems, which will actively interact with the "system" once it is operational and in use

Passive: Individuals, Entities, Other Systems, Standards, Protocols, Procedures, Regulations, which will also influence the "success" of the system

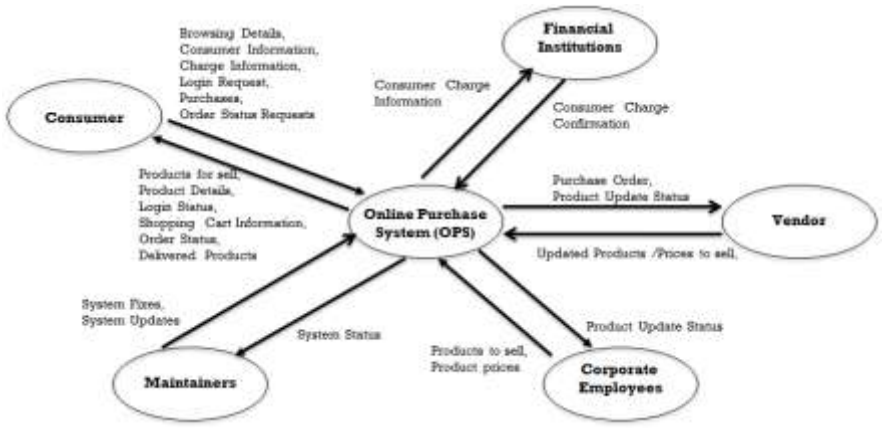
3. Choose a system from your domain and identify the list of active and passive stakeholders for this system.

Weight: 5%

List of Active and passive, following rules from question 2

4. Develop a context diagram for the above system. What are the three things that you think get clarified and communicated by a context diagram?

Weight: 15%



5. What is a stakeholder requirement? What is the difference between a stakeholder capability requirement and a stakeholder characteristic requirement? Give three examples of each from the system that you described in Question 3.

Weight: 15%

Capabilities:

1) Be able to add, change and delete products for sale at any time

2) Be able to change product prices at any time

3) Provide secure user ID and password

Characteristics:

1) Use current interface defined by the financial institution

2) Don't use too much bandwidth

3) Be operational within 6 months

6. What is a system requirement? What is the difference between a system functional requirement and a system non-functional requirement? Give three examples of each from the system that you described in Question 3.

Weight: 15%

MIL-STD 499B [Military Standard, 1993]: identifies the accomplishment levels needed to achieve specific objectives.

Chambers and Manos [1992]: the attributes of the final design that must be a part of any acceptable solution to the design problem.

Davis [1993]: a user need or necessary feature, function, or attribute of a system that can be sensed from a position external to that system.

Grady [1993]: an essential attribute for a system or an element of a system, coupled by a relation statement with value and units information for the attribute.

Harwell et al. [1993]: "If it mandates that something must be accomplished, transformed, produced, or provided, it is a requirement - period."

7. Give six attributes of a good system requirement.

Weight: 10%

1. Unambiguous
2. Understandable
3. Correct
4. Concise
5. Traced
6. Traceable
7. Design independent
8. Verifiable
9. Unique
10. Complete
11. Consistent
12. Comparable
13. Modifiable
14. Attainable

8. Describe the objective of a System Requirements Review (SRR).

Weight: 10%

Stakeholders identified, Operational requirements understood, draft spec created, draft performance defined, top level functional analysis completed, draft SEP, draft TEMP, etc.

9. What is a system functional or logical architecture?

Weight: 10%

An architecture that defines what the system must do - a partitioning of the system's top level function into sub-functions that describe the functionalities, the tasks, and/or the processing that the solution must perform.

This limited view of the functional architecture is the most common and is represented as a directed tree.

Or,

A model that augments the functional partitioning by capturing the transformation of inputs into outputs using control information. This definition adds the flow of inputs and outputs throughout the functional partitioning.

These items that comprise the inputs and outputs are commonly modeled via a data model.

APPENDIX E: COURSE EVALUATION FORM

RDECOM Advanced SE Training Assessment

Part 1: Course Evaluation

Please rate the degree to which you agree with the following statements.	Strongly Disagree - 0	Disagree - 1	Neutral - 2	Agree - 3	Strongly Agree - 4
1. The course met all of its stated objectives.	☐	☐	☐	☐	☐
2. The course was relevant to my job.	☐	☐	☐	☐	☐
3. Overall, the course materials added value to my learning experience.	☐	☐	☐	☐	☐
4. My knowledge/ skills increased as a result of this course.	☐	☐	☐	☐	☐
5. I am confident that I am able to apply knowledge/ perform skills gained.	☐	☐	☐	☐	☐
6. Overall, the course met my needs and expectations.	☐	☐	☐	☐	☐

Part 2: Instructor Evaluation

Please rate the degree to which you agree with the following statements.	Strongly Disagree – 0	Disagree – 1	Neutral – 2	Agree – 3	Strongly Agree – 4
1. The instructor related course to participants' needs and experiences.	☐	☐	☐	☐	☐
2. The instructor promoted participation discussion and engagement.	☐	☐	☐	☐	☐
3. The instructor kept the discussion on topic and the activities on track.	☐	☐	☐	☐	☐
4. Overall the instructor was effective.	☐	☐	☐	☐	☐

Part 3: Participant Comments

Questions	Response
1. What did you learn that will be most valuable to your job?	
2. What methods or techniques contributed to your learning/ engaged you most?	
3. What actions might you or others take to continue to build these knowledge/ skills?	
4. What suggestions do you have to improve the program?	
5. What topic areas would attract you to future programs?	
6. Additional Comments	

Part 4: Learning Objectives

Please rate the degree to which you agree with the following statements.	No New Learning - 0	Little New Learning - 1	Some New Learning - 2	Significant Learning - 3	Great Learning - 4
1. Translate and Explain system thinking objectives into a problem statement that can be solved by traditional engineering techniques and skill sets.	☐	☐	☐	☐	☐
2. Diagram and Discriminate the environment, system under development, and suitability of a systems solution using systems thinking approach.	☐	☐	☐	☐	☐
3. Apply systems thinking tools and techniques to better understand the enterprise and technology issues, which will affect the design of a system and translates these into system requirements.	☐	☐	☐	☐	☐
4. Evaluate and Describe customer needs, active and passive stakeholders and their perceptions of a system of interest.	☐	☐	☐	☐	☐
5. Identify essential features that are critical to satisfy customers and Distinguish where to focus further improvement efforts.	☐	☐	☐	☐	☐
6. Create a set of artifacts (i.e. Context Diagram, QFD, Pugh Matrix) that identify key drivers of customer satisfaction and needs.	☐	☐	☐	☐	☐
7. Demonstrate the concept of Use Case Scenarios to better understand the "Capabilities" that the stakeholders require.	☐	☐	☐	☐	☐
8. Translate the output from the development of use case scenarios and system objectives into system requirements and Critique the characteristics of "good" requirements.	☐	☐	☐	☐	☐
9. Comprehend the importance and the role of the system architecture and associated derived requirements in the development and project planning process.	☐	☐	☐	☐	☐
10. Assess a system of interest using the concepts and artifacts learned in class and Arrange this in a coherent and effective Review.	☐	☐	☐	☐	☐

APPENDIX F: COURSE EVALUATION FOR APG

RT29 – RDECOM Advanced SE Course Evaluation
Taught 6/25/2012 – 6/28/2012 at APG

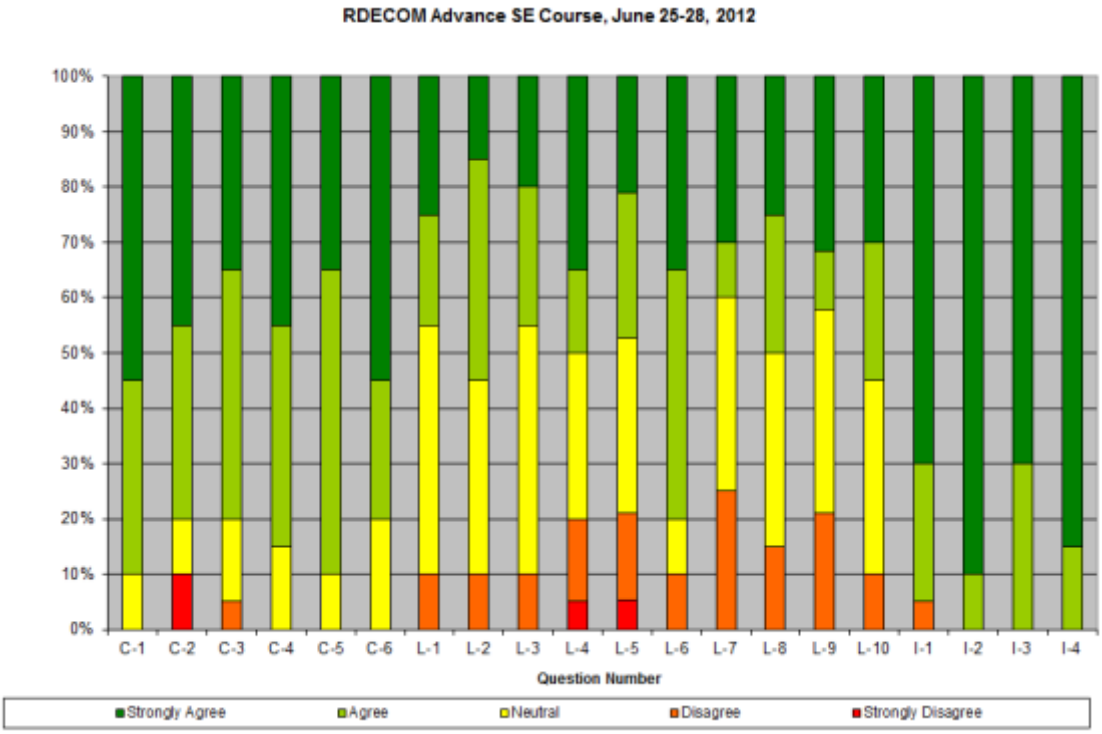


Figure 4: Summary of Student Assessment Questions (APG)

There were 6 questions about the overall course content (C-1 through C-6).

Table 5: Overall Course Content (APG)

C-1	The course met all of its stated objectives
C-2	The course was relevant to my job
C-3	Overall, the course materials added value to my learning experience
C-4	My knowledge/skills increased as a result of this course
C-5	I am confident that I am able to apply knowledge/perform skills gained
C-6	Overall, the course met my needs and expectations

There were 10 questions about the Learning Objectives for this course (L-1 through L-10).

Table 6: How well the course satisfied the Learning Objectives (APG)

L-1	Translate and Explain system thinking objectives into a problem statement that can be solved by traditional engineering techniques and skill sets.
L-2	Diagram and Discriminate the environment, system under development, and suitability of a systems solution using systems thinking approach.
L-3	Apply systems thinking tools and techniques to better understand the enterprise and technology issues, which will affect the design of a system and translates these into system requirements.
L-4	Evaluate and Describe customer needs, active and passive stakeholders and their perceptions of a system of interest.
L-5	Identify essential features that are critical to satisfy customers and Distinguish where to focus further improvement efforts.
L-6	Create a set of artifacts (i.e. Context Diagram, QFD, Pugh Matrix) that identify key drivers of customer satisfaction and needs.
L-7	Demonstrate the concept of Use Case Scenarios to better understand the “Capabilities” that the stakeholders require.
L-8	Translate the output from the development of use case scenarios and system objectives into system requirements and Critique the characteristics of “good” requirements.
L-9	Comprehend the importance and the role of the system architecture and associated derived requirements in the development and project planning process.
L-10	Assess a system of interest using the concepts and artifacts learned in class and arrange this in a coherent and effective Review.

There were 4 questions about the Instructor (I-1 through I-4).

Table 7: Instructor Effectiveness (APG)

I-1	The instructor related course to participant's needs and experience
I-2	The instructor promoted participation discussion and engagement
I-3	The instructor kept the discussion on topic and the activities on track
I-4	Overall, the instructor was effective

Figures 2 and 3 represent the average scores for each question asked, and the percent of students that answered “strongly agree” to the questions asked.

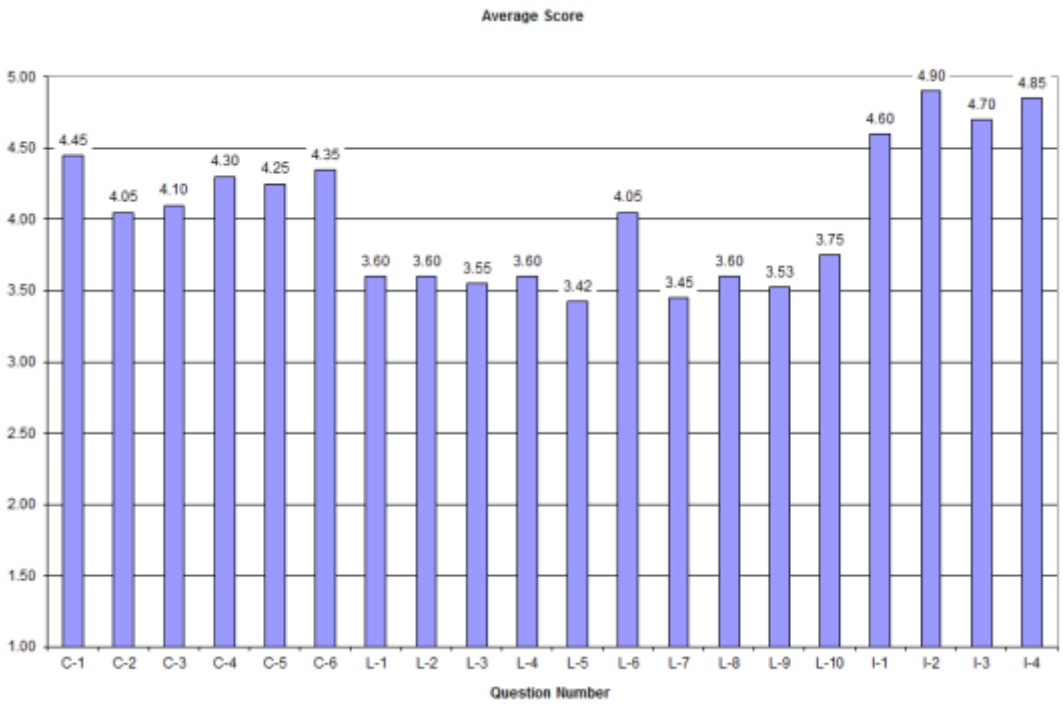


Figure 5: Average Scores on Student Assessment Questions (APG)

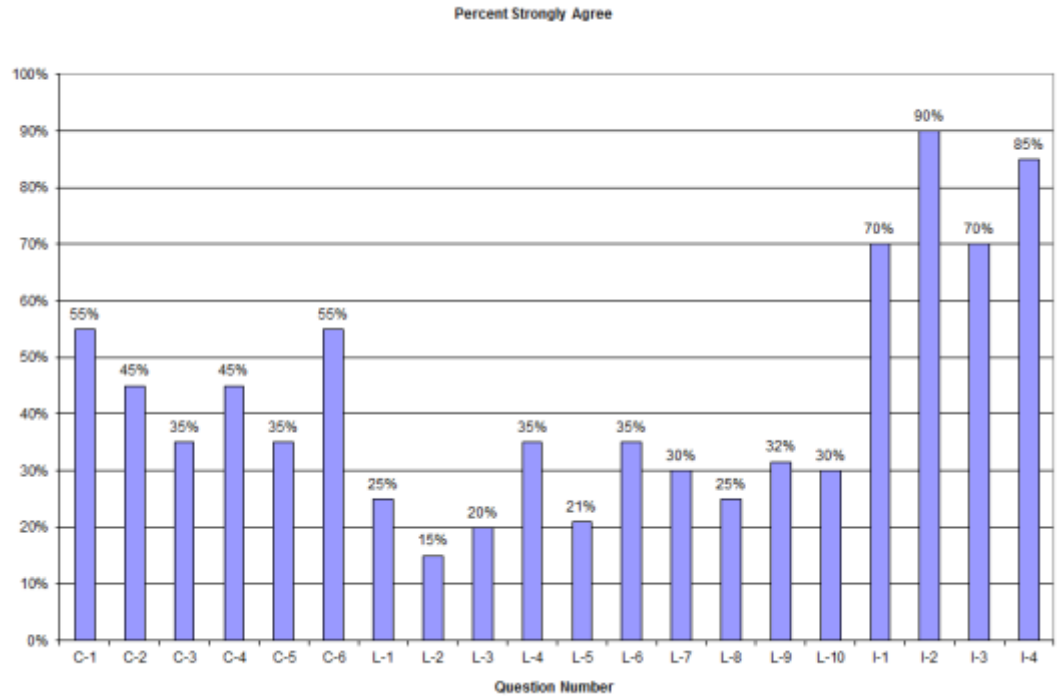


Figure 6: Percent Strongly Agree on Student Assessment Questions (APG)

Section 2: This section contains all of the qualitative comments found in Part 3 (Participation Comments) of the SE Training Assessment

1. **What did you learn that will be most valuable to your job?**
   - Methods and tools which could be applied immediately to job.
   - The details of QFD
   - Methods for capturing stakeholder needs/wants
   - Methods for Functional Decomposition
   - Context diagram
   - Considering systems/things as stakeholders
   - The "V" model and use the technique "what" to collect/generate requirements
   - The multiple tools discussed in class. Capturing the Voice of the customer.
   - I won't have cause to apply any of this in my job
   - System engineering principles
   - Various tools and feedback from other students on their thoughts
   - Breakdown process into logical steps
   - Technical review, QFD, Functional architecture
   - System engineering principles & tools
   - Requirements definition process
   - QFD and functional architecture tools
   - How to perform requirements analysis and how requirements relate to overall systems architecture
   - Rigorous process for identifying problem and turning that into requirements, system concepts, and functional architecture
   - Different tools and definitions I can apply to my job
   - Coordination w/ Stakeholders value
   - The set of artifacts (context diagrams, QFD and Systemigrams) that can be used to describe customer needs.

2. **What methods or techniques contributed to your learning/ engaged you most?**
   - The team assignment
   - Instructor lead student discussions
   - Details on System Architecture Development
   - Actively going through examples as a class (whiteboarding)
   - Group example helpful to familiarize with tools – better to work with example relevant to me
   - Systemigram, functional vs. non-functional, QFD, and Pugh matrix
   - Instructor sharing past experience and good dialogue from fellow co-workers
   - Participation group assignments
   - Exercise
   - QFD
   - QFD and functional architecture tools
   - The thinking exercises and team work initiatives
   - Exercises based on materials
   - The instructor's experience, knowledge, room presence, and enthusiasm.
   - Instructor was knowledgeable, and could convey the message clearly
   - Participating in the exercise immediately after the lecture was presented.

3. **What actions might you or others take to continue to build these knowledge/ skills?**
   - Use it on the job
   - Read the reference books in the handouts
   - Work to include these methods on my project as we are in the requirements phase of the V.
   - Follow-on topic areas (maybe ½ day courses) – ex. Architecture

- Reading materials/group discussions
- Apply directly to my project as much as I can
- Apply tools and techniques to current project and future projects. Internet searches to learn additional tools
- Attend conferences and do independent research regarding specific tools of interest
- Use this for use in reviews
- Related books and projects
- Institute on current project
- Apply tools to programs that I'm working on
- Apply tools to day to day activities as appropriate upon returning to office
- Apply these concepts to real project. When students are assigned, they should have a real need for something in the class and management support/mandate to actually implement
- Research tools and techniques provided by the instructor that will increase my SE knowledge
- This course was an overview (high level). Maybe break up course for deeper understanding of each segment
- Apply the tools immediately to current and upcoming projects

4. What suggestions do you have to improve the program?

- Use examples of RDECOM's ATO's, TECD development project
- The role of 1) Strategy, 2) Joint Modeling and Simulation, 3) Computerized Scenarios
- Change example from Amazon.com to something that includes all disciplines
- Change the RDS or add to it for more data to help
- QFD tool is out of date. QFD examples are unclear
- Define example better for group exercise. Make more relevant to audience.
- Include Object oriented architecture vs. functional. Work example of both.
- Introduce Doors & Rhapsody tools
- Directly using DoD example instead of Amazon.com
- Do a case study of a DoD project.
- Examples more relevant to RDECOM developed hardware & software
- Single work instead of group. Get a better QFD tool. Stick w/ Amazon or commercial example. DoD ones won't work. They're too complicated. Uninstall Systemitool and use visio. Requirements traceability SW use would be useful to teach. Use a PC based classroom like 6008. Provide area map of food to off-base attendees. They're your guests & spent all week eating at Burger King.
- If you insist on group work, it needs to be a) smaller groups & b) bigger monitors
- Relate more directly to CERDEC policies
- Forget the final presentation, waste of time. Learning was in group versus presentations
- A real problem to solution instead of bits and pieces
- Do not use Amazon.com example
- Exercise project could be more complex and encourage more creativity
- Sample RFI was too vague – need to select an RDECOM program.
- Use examples from real DoD programs instead of commercial projects (Amazon.com)
- Examples of artifacts to be based on Army DoD systems and not commercial products
- Don't have exercise time flow into breaks, people tend to keep going if they don't have hard deadline. Do AAR immediately after exercise, not after a break (like lunch)
- More time with the tools. Different tools besides the QFD
- Better source material. Unreadable, small print, incomplete
- Prior to beginning the course, have students select a project from their domain and use it during the course

5. What topic areas would attract you to future programs?

- All

- 1) Strategy, 2) Modeling and Simulation, 3) Computerized Scenario Development, 4) Orthogonal "mathematical" methods of best system selection
- More on Systems
- New tools, deep dives (focused). Discussion opportunities – Good, bad, ugly
- System architectures
- Emerging SE tools and best practices
- How to make your organization use this
- QFD
- Modular Open System Approach (MOSA) and DoD Architecture Framework (DoDAF)
- Completing the second leg of the "V" model
- The other side of the "V" implementation – Transition
- Tools to help the SE process. The Integration side of the SE Process
- See below
- A detailed course on the QFD process.

6. Additional Comments

- Print course material in one chart per page, not two per page
- Would like to see course on tools that our community accepts. Systemigrams work, but not in embedded into Industry as a standard
- Provide more space for comments on Assessment form
- Discussions should ask for good, bad, ugly from participants
- Questions *[on exam]* don't align to course (ex: no QFD questions or Systemigram)
- Examples are not easy to read or follow
- Provide tool kit that can be used (preferable to book of slides) – Quick Reference
- Develop or offer systems architecture and integration follow-ons
- Compositional SE would be interesting topic to do more with
- Familiarize everyone with software/IA/Security
- Did not address suitability
- Overall the course is excellent. I learned a lot even though it is too much material for 5 days course.
- Material should include previous effort examples from my agency
- Instructor was great – he sometimes was off topic & tangents, but interesting and necessary
- Don't force specific tools, offer options
- Too much material to cover – expand it into two sessions
- I suggest spending more time on developing a functional architecture
- Suggest that different project problems be assigned to different teams as a diversity when presentations are performed
- Keep Amazon.com example. It's good universal example. 99% of people are familiar with. It's a counterbalance to running project, which is Army specific.
- You can keep RFI vague but the instructor should know more and class should do VOC to elicit details. Answers should be kept in shared repository (e.g. whiteboard, shared drive, etc)
- Some items in SE should be skipped because it has been covered in DAU
- Engineers should be reminded that it is the lesson to learn not get bogged down with minor design details
- The testing aspect of the course is unnecessary. Class exercises/interactive and evaluation of the project is sufficient. Materials were absolutely horrible. Only one approach (and NOT EVEN the favored approach) was presented in the material. That cancels out the value of taking the class. Still, there was learning that occurred.
- Good course. Learned some new concepts and was refreshed on concepts that I learned in previous courses

APPENDIX G: COURSE EVALUATION FOR ARDEC

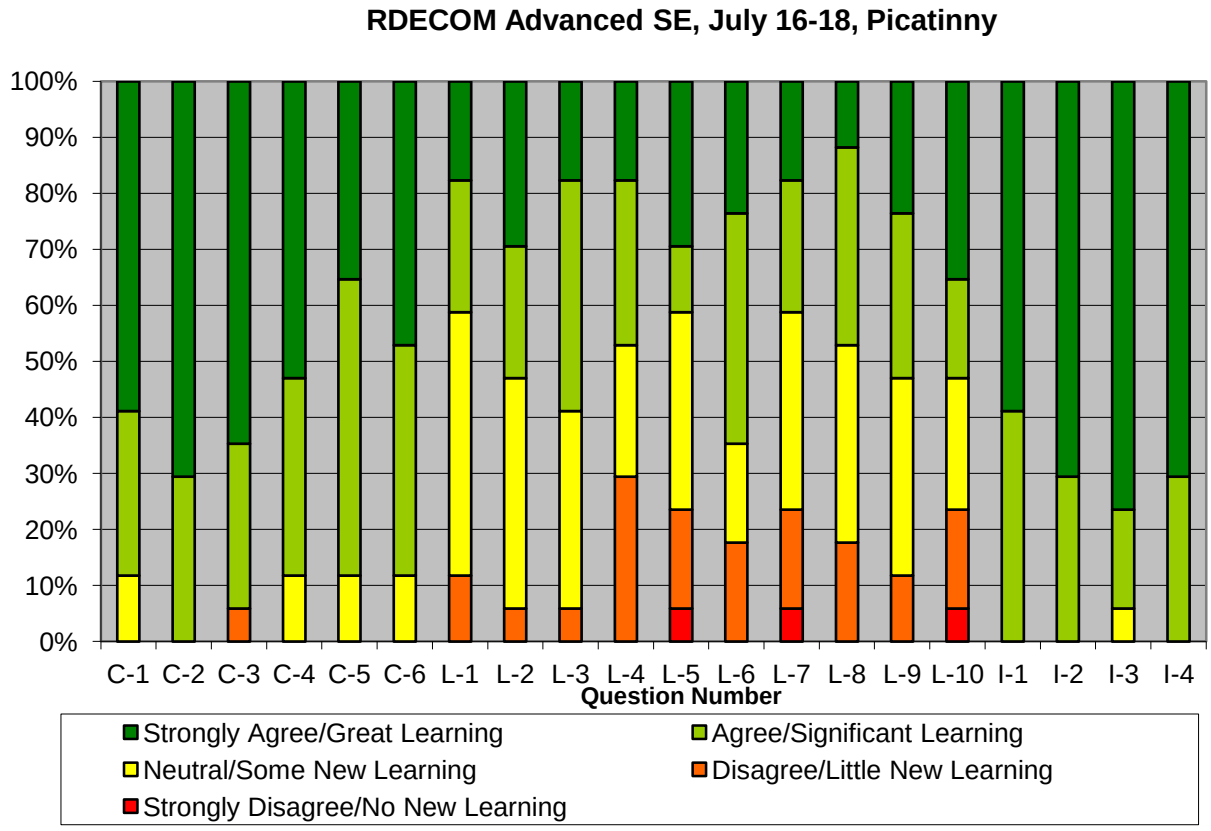


Figure 7: Student Assessments (ARDEC)

There were 6 questions about the overall course content (C-1 through C-6).

Table 8: Overall Course Content (ARDEC)

C-1	The course met all of its stated objectives
C-2	The course was relevant to my job
C-3	Overall, the course materials added value to my learning experience
C-4	My knowledge/skills increased as a result of this course
C-5	I am confident that I am able to apply knowledge/perform skills gained
C-6	Overall, the course met my needs and expectations

There were 10 questions about the Learning Objectives for this course (L-1 through L-10).

Table 9: How well the course satisfied the Learning Objectives (ARDEC)

L-1	1. Translate and Explain system thinking objectives into a problem statement that can be solved by traditional engineering techniques and skill sets.
L-2	2. Diagram and Discriminate the environment, system under development, and suitability of a systems solution using systems thinking approach.
L-3	3. Apply systems thinking tools and techniques to better understand the enterprise and technology issues, which will affect the design of a system and translates these into system requirements.
L-4	4. Evaluate and Describe customer needs, active and passive stakeholders and their perceptions of a system of interest.
L-5	5. Identify essential features that are critical to satisfy customers and Distinguish where to focus further improvement efforts.
L-6	6. Create a set of artifacts (i.e. Context Diagram, QFD, Pugh Matrix) that identify key drivers of customer satisfaction and needs.
L-7	7. Demonstrate the concept of Use Case Scenarios to better understand the "Capabilities" that the stakeholders require.
L-8	8. Translate the output from the development of use case scenarios and system objectives into system requirements and Critique the characteristics of "good" requirements.
L-9	9. Comprehend the importance and the role of the system architecture and associated derived requirements in the development and project planning process.
L-10	10. Assess a system of interest using the concepts and artifacts learned in class and arrange this in a coherent and effective Review.

There were 4 questions about the Instructor (I-1 through I-4).

Table 10: Instructor Effectiveness (ARDEC)

I-1	The instructor related course to participant's needs and experience
I-2	The instructor promoted participation discussion and engagement
I-3	The instructor kept the discussion on topic and the activities on track
I-4	Overall, the instructor was effective

Figures 2 and 3 represent the average scores for each question asked, and the percent of students that answered "strongly agree" to the questions asked.

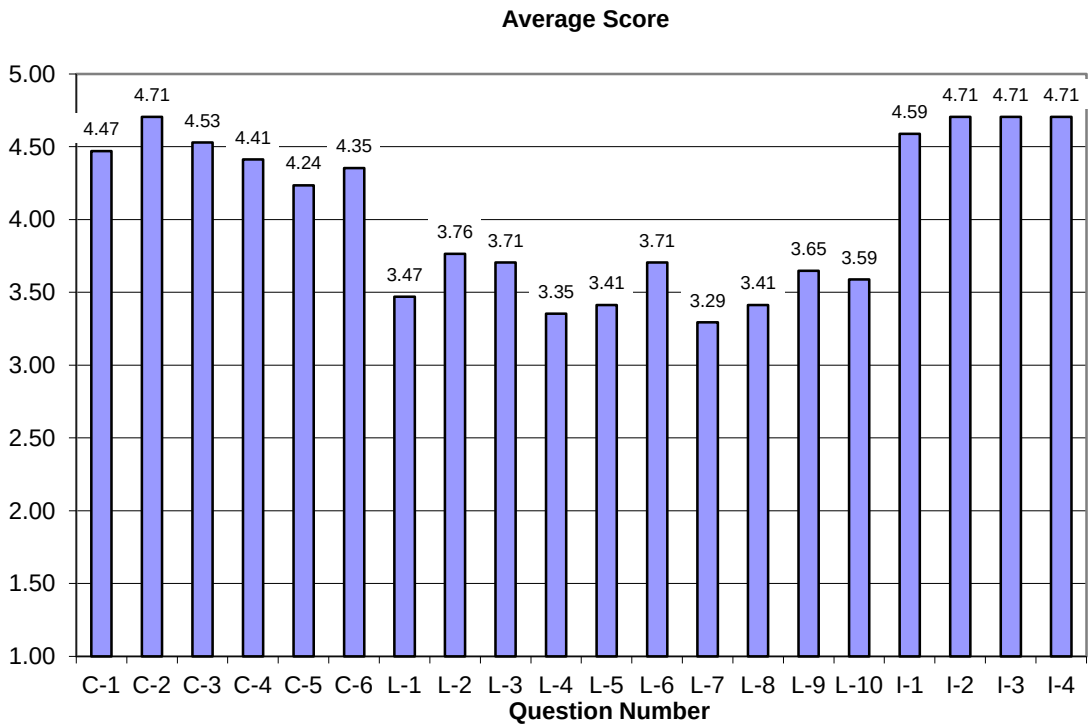


Figure 8: Average Scores on Student Assessment Questions (ARDEC)

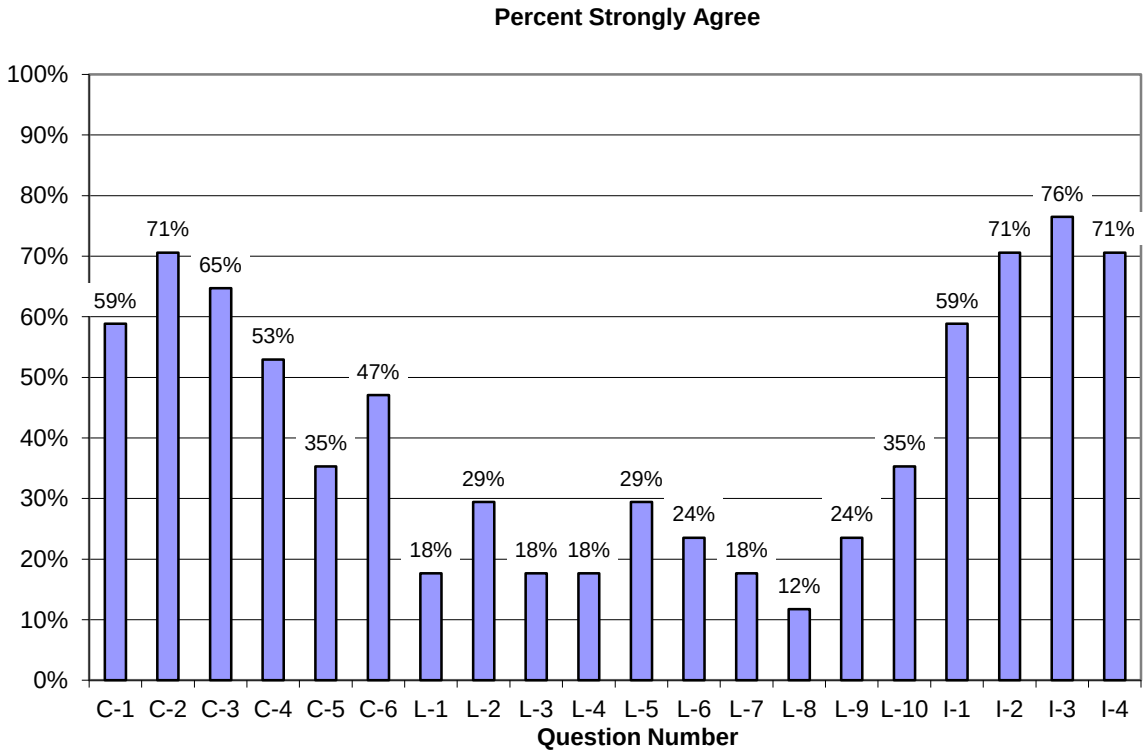


Figure 9: Percent Strongly Agree on Student Assessment Questions (ARDEC)

Section 2: This section contains all of the qualitative comments found in Part 3 (Participation Comments) of the SE Training Assessment

1. What did you learn that will be most valuable to your job?

- Functional Analysis, System Analysis
- Reinforced front end of the SE "V", will be able to review our MBSE methodology
- Effective elicitation of stakeholder rqts
- Pugh matrix for decision making
- Steps of SE
- Systemigrams, QFD
- Writing good requirements
- Refresh of SE practices and practiced portions of SE process that I haven't had experience with yet (i.e. functional analysis)
- Practical group project examples, Req. Analysis process
- The general concepts in the 3 parts of SE top down approach (SRD, RA, Arch)
- Writing good requirements
- Writing requirements
- Structured way from start to finish, exercise
- A thorough review of QFD and House of Quality
- Additional uses of QFD (i.e. find missing reqs)
- Creating good requirements

2. What methods or techniques contributed to your learning/ engaged you most?

- Systemigram, QFD
- Activity being team based
- Exercises
- Exercises helped reinforce learning
- Group exercise with practical problems
- QFD
- Functional analysis, requirement development
- Systemigram development
- The sections where we executed SE in teams on our own
- On hand development of services
- Systemigram was good, context diagram, have seen others
- Systemigram, QFD
- The examples that were used and teamwork
- Class participation
- Methods of collecting/organizing req & the tools used

3. What actions might you or others take to continue to build these knowledge/ skills?

- Keep going back and looking at material
- Be sure to apply to projects or skills will be lost
- Review and use training material
- Exercise tools on projects
- Practice on real tools
- Re-read DAG chapter 4
- Apply to the projects
- Increasing MBSE skill to apply all of these practices

- Pilot on project, utilize these tools and see if there is value in actually understanding the problem better
- Apply the knowledge gained and review material taught
- Continue to practice
- Share knowledge within program IPT
- Use class material as reference as needed
- Put it into play… and practice

4. What suggestions do you have to improve the program?

- Add some videos
- Dedicate more time to the front modules 1-3
- Assign exercises to each student on team
- More time on Systemigrams
- It only dealt with the left side of the "V"
- A little more time on tech reviews and specifics about preparation for review (i.e. artifacts required
- Offer a ½ day concentration of project type (TechD, RDP or PM) focused training does in real life
- Need to refine purpose of Systemigrams
- I think it was too fast n DASG for firsties
- Large charts, e.g. systemigram, should not be shrunken down too much
- Improve Pre-V presentations
- Nothing really, I think it is fine that we work on the left side of the "V"
- All instructors were not present at beginning, certain admin remarks were duplicated
- N/A

5. What topic areas would attract you to future programs?

- Systemigram
- MBSE enabled, completing the "V"
- Systems architecture and systems thinking
- Functional architecture
- QFD
- Should be followed with class for the right side of "V"
- The right side of the "V" should be taught including TRL and MRL assessment
- MBSE practices (applying these skills)
- Example of successful TechD & templates
- The other SE side of the "V"
- Right side of "V", and all lifecycle phases
- MBSE
- Architecture

6. Additional Comments

- Overall, very well prepped, constructed, and delivered
- SEAA (3-4 day course) should be a pre-requisite to this advanced course. SEAA provides basic essential information on the ARDEC SE process and procedure but doesn't provide details on how to use tools.
- Working on the class exercise with hands-on tools was great to grasp better understanding of how things should be done.
- Systemigram was a brand new concept which was never taught before or mentioned in any previous SE teaching. It was very confusing. It's too much in a free-form style. To be a useful tool there should be formalism put into the way it can be used. Having essential objects (boxes) to be filled out can be more beneficial. I personally don't see much use of

Systemigram for ATO or DEMO programs. It should be taught at TRADOC or Infantry School who needs to generate ICD or CDD

- Give classroom breaks at least every 90 min. It's difficult to concentrate when the session becomes too long. It also not good for the health.
- Very comprehensive – liked seeing certain principles reiterated throughout material (i.e. why are we practicing a skill/completing a task?)
- Did not see the overall value of Systemigrams. I feel their purpose should be explained in more depth. The examples for these in particular did not seem to match up well to the methodology
- QFD – Great tool
- I think more time should be spent on new concepts like the Systemigram until all participants have seen …. of it [this comment is hard to read]
- I think a sample of a good example of each class activity should be given so that the participants can see if they are missing anything
- Great course, recommend colleagues to take it.
- Since this is a pilot, timing of course and content was being assessed on the fly. Once fine tuned this course will provide an even better value. As of now, the course was valuable.
- There needs to be consistent definitions of all terms across RDECOM, ARDEC, and TARDEC call the same concepts different things.

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